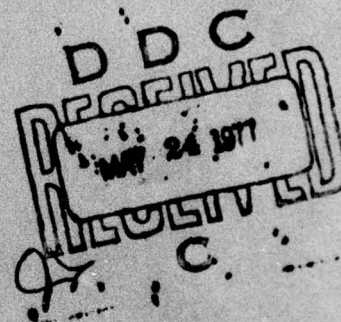AD

Report 2203

COASTAL CHARACTERISTICS AND THEIR EFFECT

ON TANKER DISCHARGE OPERATIONS

January 1977

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U.S. ARMY MOBILITY EQUIPMENT

RESEARCH AND DEVELOPMENT COMMAND

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A study has been made of three uncontrollable variables which influence the location and utility of military tanker mooring and discharge systems installed in support of military operations. The variables are: near shore gradient, current velocity, and environmental factors. Present mooring and discharge systems are found to be far from universal in their suitability for use off worldwide coastlines, a shortcoming which could periodically constrain the Tactical Commander's selection of terrain objectives. An advanced generation mooring and discharge system is proposed which
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appears well within the state of the art. The advanced system would increase coverage of world-wide landing beaches significantly, while simultaneously increasing the probability of being able to transfer fuel on a given day via an advanced system installed previously. ↑

SUMMARY

Military forces consume prodigious volumes of fuel during the conduct of combat operations. It is the fundamental mission of specific elements of the Army to insure that the Tactical Commander's actions are not constrained by an actual or a perceived shortage of fuel. Fulfilling that mission requires an integrated mix of contemporary doctrine, organizations, and materiel. This investigation concerns itself with coastal characteristics and their effect on tanker discharge operations; such operations are the initial link in the chain which connects commercial supplier to the combat user.

The coastal characteristics to be investigated are of the uncontrollable variety, meaning that their numerical values are set by natural processes beyond the control of man. The variables vary with time; and their numerical values at a given instant uniquely establish: the suitability of discrete coastal sites for tanker operations, the universality of specific design mooring and discharge systems, and the ability to transfer fuel using a system already in place. The now standard multi-leg tanker mooring (and discharge) system capabilities and the capabilities of a hypothetical, advanced, but state-of-the-art system were compared with the worldwide coastal data; and the following conclusions were drawn:

a. The standard system would be usable off a randomly selected landing beach approximately 47 percent of the time compared with 71 percent for the advanced system if nearshore gradient alone is considered.

b. The standard system would be usable off a randomly selected landing beach approximately 56 percent of the time compared with 88 percent for the advanced system if current velocity alone is considered.

c. Once installed, the standard system would be usable approximately 40 percent of the time during the worst month of the year and 70 percent of the time on an annual average if upper seastate limit alone is considered; an advanced system would be usable approximately 63 percent of the time during the worst month and 85 percent on an annual average.

d. The statistical distributions of the three variables are at least partially correlated so that the probability of a given landing beach being compatible with the capabilities of a given mooring and discharge system and their probability of delivering fuel from a vessel positioned off a randomly selected landing beach on a randomly selected day must be represented as a range of values pending the acquisition of additional data. If the first of the two is termed "site compatibility" and the second termed "universality/operability," the standard system would be site-compatible off-

shore from between 20 and 50 percent of worldwide landing beaches, compared with between 60- and 70-percent coverage for the advanced system. Taking annual seastate occurrence rates into account, the universality/operability of the standard system would range between 18 and 47 percent compared with a range of 53 and 71 percent for the advanced system.

e. The limited universality/operability of the standard system requires the use of more tankers, discharge systems, and onshore gathering systems than would be required should the hypothetical system be available to the Tactical Commander as a substitute.

f. The hypothetical advanced mooring and discharge system described herein appears to offer greater flexibility to the Tactical Commander than does the standard system; the advanced system would appear to simultaneously reduce the number of systems needed to support a given fuel demand, thereby reducing the resources required to procure, install, and operate those systems.

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COASTAL CHARACTERISTICS AND THEIR EFFECT
ON TANKER DISCHARGE OPERATIONS

I. INTRODUCTION

1. Introduction. The bulk fuel used by military forces in time of conflict will generally be delivered to the conflict area in large ocean-going tankers chartered and controlled by the Military Sealift Command (MSC). The discharge of fuel from such vessels is subject to two fundamental conditions: (a) The suitability of a given portion of coastline in terms of physically accommodating a tanker, mooring, and conduit; and (b) the local situation given a tanker which is physically moored offshore and coupled to shore through a conduit. The first condition applies when the entire coastline within a theater of operations is examined and only some finite number of points along the coastline are found which lend themselves to the mooring and discharge of a tanker through a conduit; i.e., the probability of a randomly selected coastal site accommodating a tanker and conduit is less than 1. The second condition arises after one or more sites are selected, all fixed elements are in place, and a loaded tanker is physically available for discharge; i.e., the probability of actually discharging a tanker on a randomly selected day or hour is less than 1.

If the basic mission of petroleum supply is *to insure that the Tactical Commander's actions are not constrained by an actual or perceived shortage of fuel*, then the task for which the offshore portions of a bulk fuel delivery system must be designed is to *insure that sufficient fuel is delivered ashore to meet the demands imposed by friendly forces, to include the accumulation of a fuel reserve adequate to sustain the force during those periods when it is not possible to move additional fuel ashore.* A parallel concern is that the site requirements are not so restrictive as to severely limit the number of suitable sites. Such a situation could possibly result in logistical site acquisition objectives preempting acquisition of tactically superior objectives. The problem then becomes one of evolving an offshore discharge system which exhibits the greatest degree of universality consistent with the countervailing urge for a reduction of sophistication, cost, and labor intensivity. The problem may be modeled in its most basic form as follows:

$$P = P_A \times P_B, \qquad (1)$$

where:

P is the probability of delivering fuel from a vessel positioned off a randomly selected landing beach on a randomly selected day,

P_A is the probability of a randomly selected landing beach being physically compatible with tanker discharge operations given a tanker mooring and discharge conduit of finite and specified capability, and

P_B is the probability of discharging a tanker on a randomly selected day given the prior existence of a suitable mooring and discharge conduit.

It is now appropriate to investigate the variables which are constituent elements of P_A and P_B as previously defined as well as the standard systems developed for the mooring and discharge function. Such an investigation must begin with an understanding of tankers, to include their capabilities and limitations. Tankers in the Military Sealift Command (MSC) fleet presently range from 25,000 to 35,000 deadweight tons (DWT) (22,680 to 31,751 metric tons) in size; the standard system (multi-leg tanker mooring system) is limited to tankers at the low end of this range, i.e., 25,000 DWT (22,680 metric tons). A fully loaded tanker of any size within that range penetrates approximately 35 feet (10.7 meters) into still water. Additional water depth must be provided to accommodate tidal fluctuations and wave-induced vertical hull motions (heave). Thus, 45 feet (13.7 meters) of water depth becomes the absolute minimum depth for purposes of planning tanker operations.

II. DISCUSSION

2. **Nearshore Gradient.** The world's coastlines vary substantially in terms of suitability for nearshore tanker operations. A given coastline may have numerous, few, or no harbors; and those harbors that exist may be either natural or artificial. Even when harbors suitable for tankers exist, the Commander must decide if their convenience is worth the risk to other facilities within the harbor area. Consider the situation where a hostile force succeeds in destroying a tanker within the harbor and, thereby, unleashes a potentially devastating layer of fuel floating on the harbor surface where it threatens other shipping, supplies, and port facilities; ammunition ships pose a similar hazard when serviced in harbors accommodating a variety of port operations. The use of existing ports is predicated, therefore, upon the following: (a) Ports actually exist which are technically adequate; (b) ports have been made available to US forces, i.e., they are not singularly essential to support the civilian economy, or they are of such size as to jointly service military *and* civilian functions; (c) existing ports have not been destroyed by either friendly or hostile forces prior to arrival of US forces; and (d) vessels within a harbor are relatively immune to interdiction by hostile forces, be this because of local air superiority or a local concentration of air defense weaponry.

The alternative to harbor operations is operation across an undeveloped coastline. It should be noted that worldwide coastlines vary markedly in terms of their

physical characteristics. For example, a rugged coastline with sea cliffs and offshore obstacles would not constitute a good site. In contrast, a sandy beach of adequate size, with access inland, and which allows vessels to approach reasonably close to the shoreline would be highly desirable; those beaches which are suitable for military amphibious operations (both of an assault and logistical nature) are hereafter referred to by the generic term, "landing beaches." The point regarding nonharbor operations is simply that coastline physical attributes vary significantly; therefore, over-the-shore movement of personnel or materiel may be conducted only along *some fraction* of the world's coastlines. The specific fraction may vary substantially from one coastal sector to another since local climatology and geology jointly determine the nature of the local coastal features. The variability necessitates the deliberate and thoughtful analysis of potential landing beaches during the preliminary planning phase of a military operation. For example, the actual beach chosen physically dictates the closest distance to which tankers and cargo vessels may approach. A landing beach whose offshore extension has a relatively flat seabottom slope (gradient) would preclude vessels from approaching as close to shore as would be possible if a beach with a steeper gradient were chosen. Therefore, the choice of beach is observed to have a significant impact on the ultimate choice of cargo discharge system; a sufficiently flat gradient would preclude the use of offshore causeways or pipelines. In such cases, shallow draft vessels might be employed to shuttle cargo to shore; however, shuttling is a very capital- and labor-intensive approach particularly as vessels are positioned further and further from shore — along one actual coastline the distance to the 45-foot (13.7-meter) water depth contour varies between approximately 1 and 10 miles (1.6 and 16.1 kilometers) with the longer distances predominating.

As the distance between ship and shore decreases, alternatives to shuttling become increasingly amenable. For example, cargo vessels may be unloaded from portable causeways if the seabottom slope allows the vessel to approach sufficiently close to shore. Given approach distances beyond those practical for efficient causeway operation but within 5,000 feet (1,524 meters), tankers may be discharged with aid of existing pipelines and hoselines; however, shuttling is the only alternative now available if a tanker's nearest approach is greater than 5,000 feet (1,524 meters) of shore. It should be cautioned that even this limited capability is conditional upon the 45-foot (13.7-meter) water depth contour being no further than 3,750 feet (1,143 meters) from shore. This additional constraint finds its origin in the poor maneuverability of tankers; safe operation of tankers dictates that the appropriate depth of water, 45 feet (13.7 meters) in this case, be provided for approximately 1,250 (381 meters) shoreward of the point where the vessel will be positioned during the actual discharge of cargo. The 1,250 feet (381 meters) between the 45-foot (13.7-meter) depth contour and tanker provides a safety zone in which the tanker may maneuver without danger. The zone provides a measure of insurance against catastrophe by preventing the tanker from grounding: (a) Should it override the mooring during initial entry, (b) should the mooring fail and the tanker drift toward shore, or (c) should the tanker lose power

unexpectedly when arriving or departing the mooring.

The distance from shore to the 45-foot (13.7-meter) depth contour will vary dramatically from one beach to another; therefore, only some percentage of beaches will have 45 feet (13.7 meters) of water depth within the presently required 3,750 feet (1,143 meters) of shore. If the conduit length is increased incrementally beyond the current 5,000-foot (1,524-meter) limit, it would be possible to discharge tankers moored off an increasing percentage of landing beaches. In sum, the percentage occurrence of the required water depth offshore from worldwide landing beaches would increase as the conduit length increased. The significance of this is that an otherwise excellent landing beach may not allow the direct; i.e., by means other than shuttle, discharge of tankers because the available conduit (now limited to 5,000 feet (1,524 meters)) could not extend to the 45-foot (13.7-meter) depth contour plus 1,250 feet (381 meters) off all landing beaches. The clear implication is that *the longer the conduit, the larger the percentage of landing beaches which could be serviced given a specific discharge system;* a complementary observation is that the longer the conduit length, the smaller the percentage of the time that shuttling would be required.

A knowledge of worldwide landing beach gradients would do much to objectively demonstrate the relative merits of conduits whose lengths comprise a continuum ranging from very short to very long. The raw data supporting such an inquiry are available from two primary sources – the CIA and DIA. The CIA publishes the National Intelligence Survey (NIS), one portion of which identifies landing beaches along the majority of the world's coastlines; a compilation and analysis of the NIS landing beach data has already been performed by a navy investigator.[1] A more recent and ongoing effort presented here for the first time derives its data from a series of documents generated by and/or in cooperation with the DIA, i.e., Amphibious Objective Studies (AOS), Special Amphibious Studies (SAS), and Amphibious Area Studies (AAS). (See the appendix for a listing of the individual source documents screened.) The two efforts present their findings in the form of cumulative probability curves. Figure 1 is the curve produced using the preliminary DIA data; the dashed lines indicate that finding water of 45-foot (13.7-meter) depth within 3,500 feet (1,066.8 meters) of shore is expected to occur only 50 percent of the time. The curve shape is also indicative of the problem which inherently prevents conduits of "practical" length in a military sense from achieving true universality. As the conduit length increases, the conduit may be used off a progressively higher percentage of landing beaches, *but* the rate of increase in potential applicability slows with increasing conduit length. Thus, as the length of a conduit increases, so does the probability that the conduit may be usable off a randomly selected landing beach, but doubling the potential conduit length will result in less than a doubling of the probability of its being useful. In

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[1] D. P. Scott, *Statistical Properties of Assault Landing Beaches (U)* (Classified Confidential), Naval Ship Research and Development Laboratory, Panama City, Florida, January 1969.

CUMULATIVE PROBABILITY OF OCCURRANCE (%)

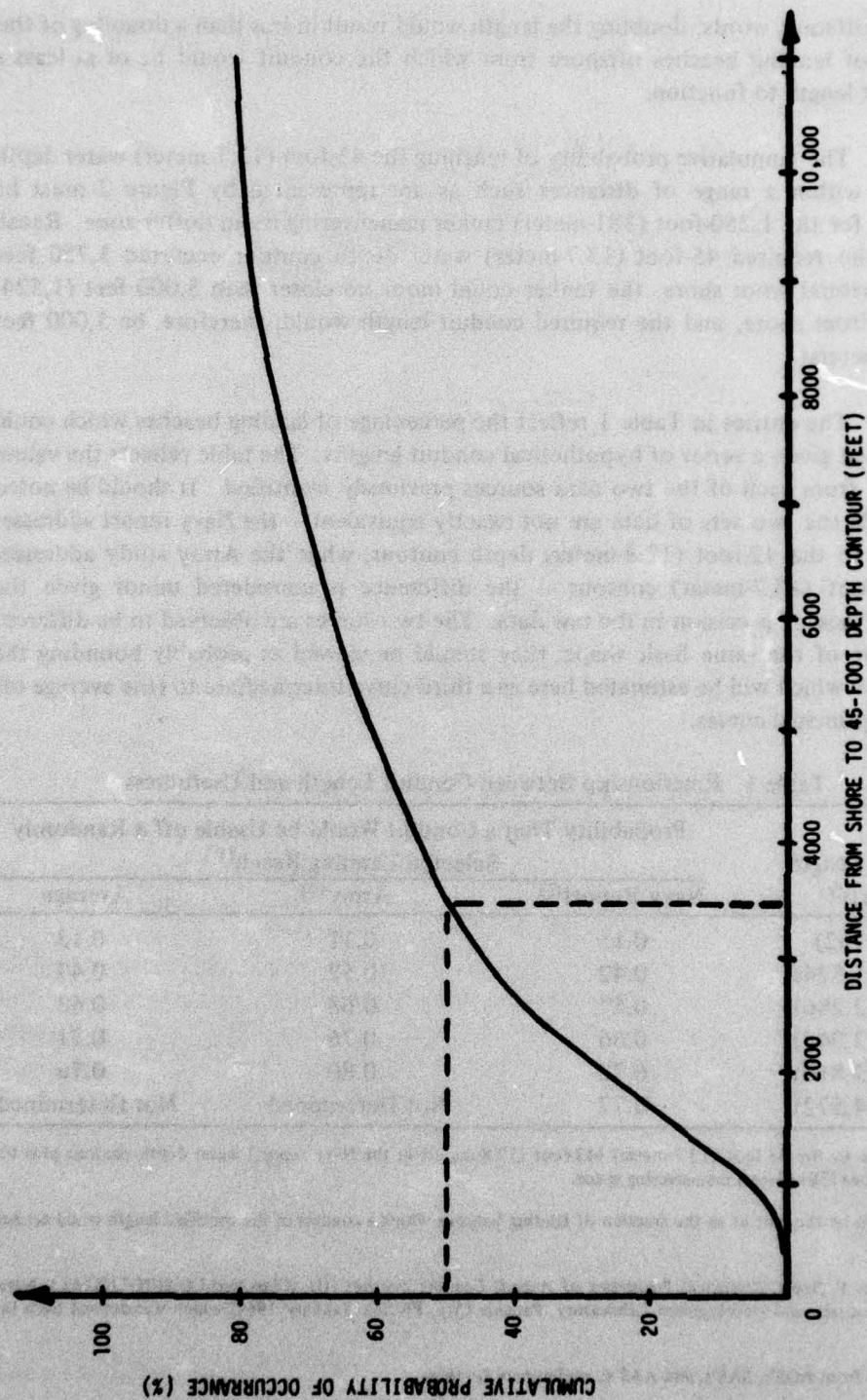DISTANCE FROM SHORE TO 45-FOOT DEPTH CONTOUR (FEET)

Figure 1. Cumulative probability of encountering the 45-foot (13.7-meter) water depth contour within a range of distance from shore.

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slightly different words, doubling the length would result in less than a doubling of the number of landing beaches offshore from which the conduit would be of at least a sufficient length to function.

The cumulative probability of reaching the 45-foot (13.7-meter) water depth contour within a range of distances such as are represented by Figure 2 must be adjusted for the 1,250-foot (381-meter) tanker maneuvering room buffer zone. Recall that if the required 45-foot (13.7-meter) water depth contour occurred 3,750 feet (1,143 meters) from shore, the tanker could moor no closer than 5,000 feet (1,524 meters) from shore, and the required conduit length would, therefore, be 5,000 feet (1,524 meters).

The entries in Table 1 reflect the percentage of landing beaches which could be serviced given a series of hypothetical conduit lengths. The table reflects the values obtained from each of the two data sources previously identified. It should be noted that while the two sets of data are not exactly equivalent — the Navy report addresses distance to the 42-foot (12.8-meter) depth contour, while the Army study addresses the 45-foot (13.7-meter) contour — the difference is considered minor given the inherent lack of precision in the raw data. The two curves are observed to be different but to be of the same basic shape; they should be viewed as probably bounding the true curve which will be estimated here as a third curve intermediate to (the average of) the two principal curves.

Table 1. Relationship Between Conduit Length and Usefulness

Conduit Length (ft (m))[a]	Probability That a Conduit Would be Usable off a Randomly Selected Landing Beach[b]		
	Navy Report[c]	Army[d]	Average
1,500 (762)	0.15	0.11	0.13
5,000 (1,524)	0.42	0.52	0.47
7,500 (2,286)	0.57	0.68	0.63
10,000 (3,048)	0.66	0.76	0.71
12,500 (3,810)	0.72	0.80	0.76
15,000 (4,572)	0.77	Not Determined	Not Determined

[a] Distance to the 45 foot (13.7-meter) (42-foot (12.8-meter) in the Navy report) water depth contour plus the 1,250-foot (381-meter) maneuvering space.

[b] May also be thought of as the fraction of landing beaches which a conduit of the specified length could accommodate.

[c] From D. P. Scott, *Statistical Properties of Assault Landing Beaches* (U), (Classified CONFIDENTIAL), Naval Ship Research and Development Laboratory, Panama City, Florida, January 1969, which was derived from the NIS.

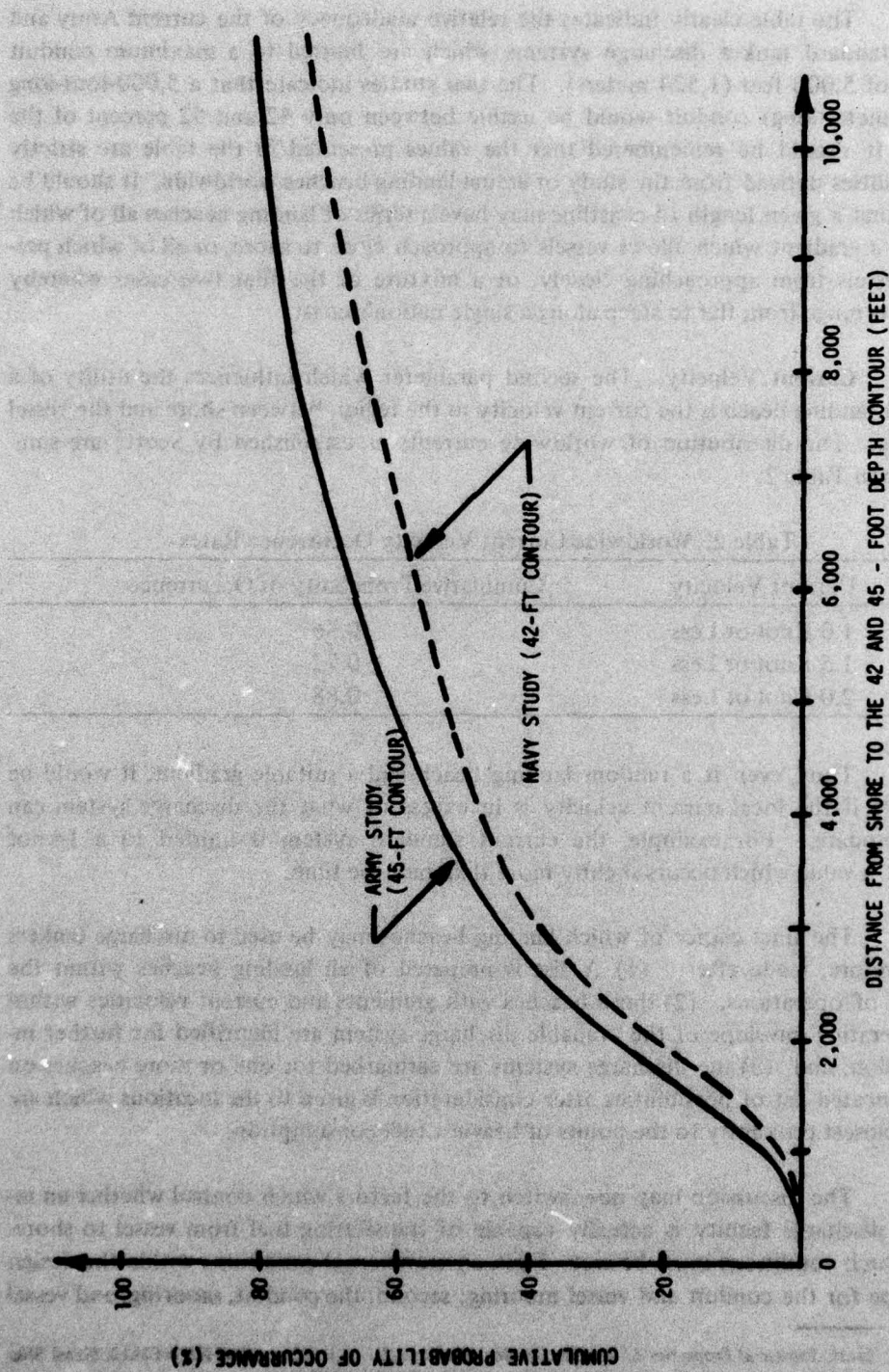[d] Derived from AOS's, SAS's, and AAS's; preliminary findings.

Figure 2. Cumulative probability of encountering the specified water depth contour within a range of distances from shore.

The table clearly indicates the relative inadequacy of the current Army and Navy standard tanker discharge systems which are limited to a maximum conduit length of 5,000 feet (1,524 meters). The two studies indicate that a 5,000-foot-long (1,524-meter-long) conduit would be usable between only 42 and 52 percent of the time. It should be remembered that the values presented in the table are strictly probabilities derived from the study of actual landing beaches worldwide. It should be noted that a given length of coastline may have a series of landing beaches all of which possess a gradient which allows vessels to approach close to shore, or all of which prevent vessels from approaching closely, or a mixture of the first two cases whereby gradients range from flat to steep along a single nation's coast.

3. **Current Velocity.** The second parameter which influences the utility of a random landing beach is the current velocity in the region between shore and the vessel mooring. The distribution of worldwide currents as established by Scott[2] are summarized in Table 2.

Table 2. Worldwide Current Velocity Occurrence Rates

Current Velocity	Cumulative Probability of Occurrence
1.0 Knot or Less	0.56
1.5 Knot or Less	0.72
2.0 Knot or Less	0.88

Thus, even if a random landing beach had a suitable gradient, it would be unusable if the local current velocity is in excess of what the discharge system can accommodate. For example, the current standard system is limited to a 1-knot current, a value which occurs slightly more than half the time.

The final choice of which landing beaches may be used to discharge tankers is, therefore, made after: (1) A list is prepared of all landing beaches within the theater of operations, (2) those beaches with gradients and current velocities within the operating envelope of the available discharge system are identified for further investigation, and (3) the discharge systems are earmarked for one or more beaches on the truncated list of possibilities after consideration is given to the locations which are in the closest proximity to the points of heaviest fuel consumption.

The discussion may now switch to the factors which control whether an installed discharge facility is actually capable of transferring fuel from vessel to shore. Three such conditions must be met: First, environmental conditions within the design envelope for the conduit and vessel mooring; second, the conduit, mooring, and vessel

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2 D. P. Scott, *Statistical Properties of Assault Landing Beaches (U)* (Classified CONFIDENTIAL), Naval Ship Research and Development Laboratory, Panama City, Florida, January 1969.

pumps operable; and, third, fuel storage tanks on shore are partially empty. The first factor is dependent upon the actual site chosen, while the others are substantially independent of the site and should be approximately constant for any discharge facility.

4. **Environmental Factors.** In the sense intended here, environmental factors refer to the wave and wind climatology off individual landing beaches. Both waves and wind interact with tankers, be the tankers moving or moored. For example, if the seastate — a measure of wave height and, therefore, intensity — becomes elevated beyond a certain level, it would not be physically possible to moor a tanker. Therefore, it would be physically impossible to discharge fuel which could either be in adequate or short supply at that particular moment. Should the seastate become elevated beyond a certain value while a tanker is discharging its cargo, the discharge operation would have to be terminated prematurely with the tanker moving further offshore until conditions subside.

The forces imposed on a vessel mooring increase with increasing seastate and with increasing wind velocity. Local winds may generate waves (sea), but those waves will generally have relatively short wavelengths and, therefore, have little effect on a tanker. However, the local winds may be of sufficient magnitude to require aborting a discharge mission even though the sea may not be a problem. Waves generated by distant storms will tend to selectively propagate longer waves (swell) which may interact strongly with a free or moored tanker, introducing very substantial mooring loads in the latter case. It is possible that the occurrence of high local winds could coincide with the arrival of swell originating from some distance; such a situation would generate the maximum mooring forces and, thereby, produce the maximum probability of aborting the discharge operation. If seastate alone is considered as the controlling element for purposes of facilitating the analysis, the occurrence rates of various seastates may be established from a study of worldwide data.[3] Such an investigation leads one to the qualitative conclusion that the occurrence of elevated sea conditions is not uniformly distributed throughout the year but, rather, is monomodal or bimodal, i.e., exhibits a peak value during one or two not consecutive months, while the incidence rate during the remainder of the year will generally be a much lower value. A seastate incidence model has been formulated around this observed nonuniformity. Seastate data have been gathered from a number of worldwide sites in terms of annual averages and worst months, i.e., months in which a given level of seastate occurs with the greatest frequency. Figure 3 illustrates the two relationships as a function of wave height. The annual data are observed to emphasize the smaller waves while simultaneously deemphasizing the larger waves. This occurs since the highest waves typically occur during only one or two months of the year and infrequently even then.

[3] F. M. Cavasco, *Multi-Leg Tanker Mooring System and Unloading Facility: System Model and Reliability Analysis*, Report 2163, US Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia, January 1976.
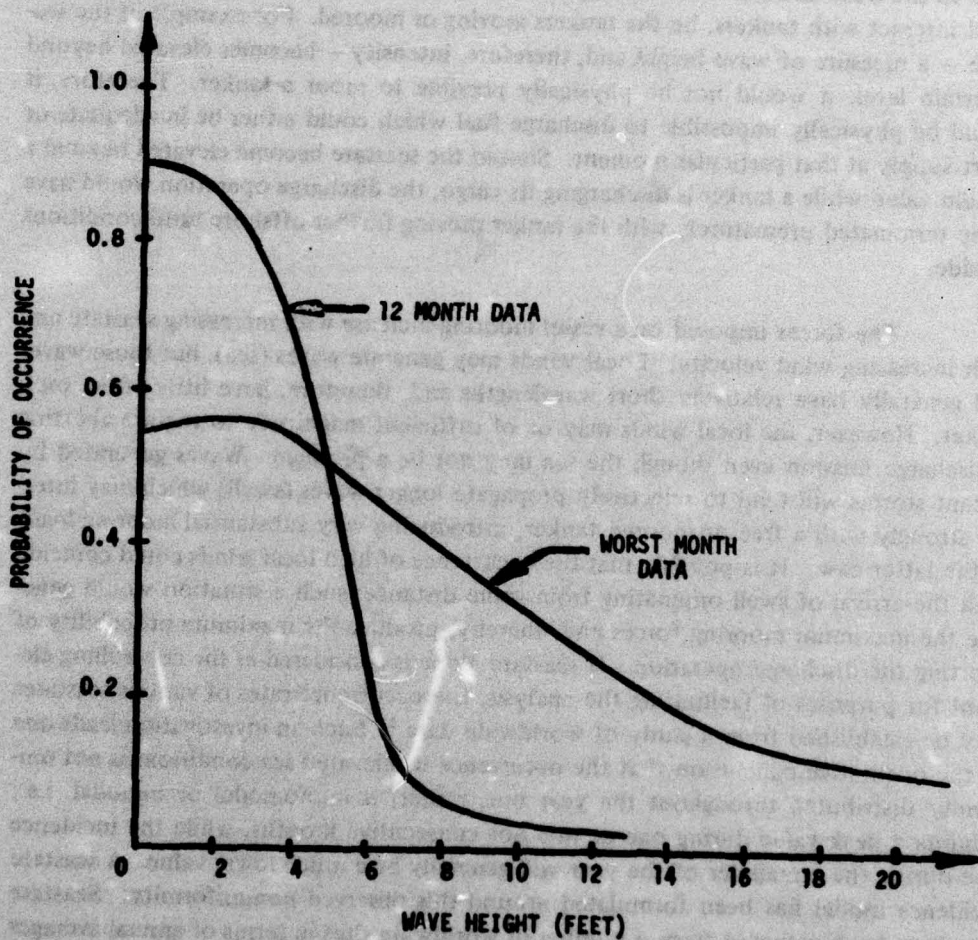
Figure 3. Probability of given wave heights occurring on a monthly and annual basis.

Axis labels: PROBABILITY OF OCCURRENCE; WAVE HEIGHT (FEET); curve labels: 12 MONTH DATA, WORST MONTH DATA.

Thus, if the few observations are averaged over an entire year, the computed probability will be numerically small; however, if the few observations are averaged over the month in which they occur, their incidence will be magnified proportionately. The worst month distribution curve is, therefore, observed to be skewed toward the higher waves, the reason for which should now be readily appreciated.

If the impact of elevated seastates is examined in the context of the existing mooring and discharge system, one finds an upper operating limit of seastate 2. Thus, the existing system would be operable 40 percent of the time during the worst month of the year and 70 percent of the time for the remaining 11 months. The relative merits of increasing the seastate tolerance are made readily evident through inspection of the values in Table 3.

Table 3. Worldwide Seastate Occurrence Rate

Upper Seastate Limit	Probability of Being Operational in:	
	Worst Month	Remaining Months
2	0.40	0.70
3	0.63	0.85

III. ANALYSIS

5. **Analysis.** The principal factors which influence the relative universality of a tanker discharge system have now been addressed. The model presented as equation (1) may now be expanded to incorporate each of the factors discussed as well as two others which are of major importance:

$$P = P_G \times P_C \times P_w \times R + C, \qquad (2)$$

where:

P   is the probability of delivering fuel from a vessel positioned off a randomly selected landing beach on a randomly selected day;

P_G is the probability of the offshore gradient being compatible with the maximum conduit length;

P_C is the probability of the current velocity being within the design envelope;

P_w is the probability of the environmental factors (wind and wave) being within the design envelope;

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R   is the reliability of the conduit, mooring, and vessel pumps; and

C   is an adjustment which compensates for any correlations among P_G, P_C, P_w, and R.

The reliability, which may be best visualized in terms of the mean time between failure, impacts directly upon the fuel transfer operation since no fuel may be conveyed through a system which has physically malfunctioned even though the gradient, current velocity, and environmental parameters may all be within acceptable limits. Reliability, while an important factor, will not receive further attention within this report; the reader interested in such matters is referred to an earlier report from which this derived.[4]

Thus, before fuel may be transferred from a tanker to shore off a randomly selected landing beach on a randomly selected day, four conditions corresponding to the first four terms on the right side of equation (2) must be satisfied. The sequential multiplication of a series of numbers, all of which are less than 1.0, inherently produces a result which is numerically less than any of the constituents. Consider a variation of equation (2) which is applicable once a site has been selected and a discharge facility installed:

$$P' = P_w \times R + C',\tag{3}$$

where:

P'   is the probability of delivering fuel from a vessel on a randomly selected day utilizing an existing discharge facility;

P_w is the probability of the environmental factors (wind and wave) being within the design envelope;

R   is the reliability of the conduit, mooring, and vessel pumps; and

C'   is an adjustment which compensates for any correlations between P_w and R.

The reader is cautioned about overreacting to the numerical values for P and P' obtained by the simple multiplication of the individual values previously presented in the figures and tables. The individual values represent the estimated probability of

[4] F. M. Covasco, *Multi-Leg Tanker Mooring System and Unloading Facility: System Model and Reliability Analysis*, Report 2163, US Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia, January 1976.

occurrence; however, there may be a relationship among them. For example, it is reasonable to posit a relationship between the gradient and the probability of experiencing elevated seastates. While the two-dimensional data required to test this particular hypothesis are not currently available, existence of the postulated relationship must be acknowledged before computing estimated values for P and P'. The overall probability of transferring fuel would be artificially depressed should equations (2) or (3) be applied without knowledge of the correction factor. For purposes of illustration, it is of interest to investigate the universality of the current multi-leg tanker mooring system in terms of equation (2):

$$P = P_G \times P_c \times P_w \times R + C$$
$$= 0.47 \times 0.56 \times 0.70 \times R + C = 0.18 \times R + C.[5]$$

The results show that for reliabilities close to 1.0 there is only one chance out of five of discharging a tanker off a randomly selected landing beach on a randomly selected day using the current standard system; however, if P_c and P_w were strongly correlated with P_G, the product of the first three terms would be close to the P_G value, raising the numerical result to a theoretical maximum of 0.47 given the earlier reliability assumption. The inherent uncertainty makes it appropriate to express P values in the form of ranges using P_G as the basic variable, while P_c and P_w are relegated to a lesser status. The preceding is an admittedly heuristic argument but is consistent with the preliminary nature of this investigation.

IV. CONCLUSIONS

6. **Conclusions.** The capabilities of the present system and a hypothetical advanced generation system are presented in Table 4 for purposes of comparison.

Table 4. Comparison of System Capabilities

Parameter	System Capability	
	Present	Target
Seastate	2	3
Current Velocity (kts)	1	2
Conduit Length (ft (m))	5,000 (1,524)	10,000 (3,048)
Tanker Size (DWT (metric tons))	25,000 (22,680)	38,000 (34,473)

If the above capabilities are transformed into probabilities and the resultant values substituted into equations (2) and (3), one obtains the measures of utility listed in Table 5.

[5] The value of 0.70 for P_w is the annual probability of experiencing seastate equal to or less than seastate 2.

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Table 5. Fuel Transfer Probabilities

	Probability of Being Able to Transfer Fuel, Given:	
Parameter*	Present System	Advanced System
P	0.18 – 0.47	0.53 – 0.71
P'	0.70	0.85

* For annual occurrence rates of seastates above the upper operational limit.

It is apparent that a totally universal tanker discharge system (P = 1.00) which the Tactical Commander may direct to be placed on any landing beach and which is continuously on call is not physically achievable; however, an advanced generation system which provides a relatively high probability ($0.80 \leq P' \leq 1.00$) of being operational once installed appears feasible. If planners are willing to accept the need to carefully scrutinize coastlines for prospective tanker discharge facilities, the seastate keeping capability and system reliability then control how much of the time the discharge system is truly available for use. However, it is simultaneously desirable to reduce the initial site selection constraints from their current levels. The latter reduction would offer planners the greatest likelihood of placing needed facilities in close proximity to the coastal locations which coincide with maximum fuel consumption as well as at those points where major lines of communication extend from the coast to forces concentrated inland.

It is evident that an advanced system would make its greatest contribution by allowing the Commander a greater choice in locating his tanker discharge facilities and in the enhanced operability during the worst month of the year. From Tables 1 and 2 it may be estimated that the present system could be installed offshore from approximately 20 to 70 percent of worldwide landing beaches, while the advanced system would be suitable for use offshore from 60 to 70 percent of the same list of beaches. If the advanced system also embodied enhanced seastate tolerance, the values recorded in Table 5 indicate that it would be compatible *and* operable for between 53 and 71 percent of the possible combinations of coastal sites and times. This stands in significant contrast with the lesser 18- to 47-percent range recorded for the present system.

The decreased site selection constraints would magnify the Tactical Commander's options, perhaps alleviating the need for him to capture terrain for purely logistical motives. The cumulative increase in the time the advanced system is functional vis-a-vis the current system would reduce the number of systems required to support a given hostility. Both advantages presented are judged as being highly desirable from a cost-operational effectiveness viewpoint.

APPENDIX

SOURCE DOCUMENTS

1. DIA Pub AP-1-385-1-9-65 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

2. DIA Pub AP-1-385-1-10-65 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

3. DIA Pub AP-1-385-1-14-65 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

4. DIA Pub AP-1-385-1-17-66 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

5. DIA Pub AP-1-385-1-15-65 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

6. S-158-63, Special Amphibious Study (SAS) (U) (Classified SECRET).

7. DIA Pub AP-1-385-1-16-66 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

8. DIA Pub S-62-63, Amphibious Objective Study (AOS) (U) (Classified SECRET).

9. DIA Pub AP-1-385-1-13-65 Int, Amphibious Objective Study (AOS) (U) (Classified SECRET).

10. DIA Pub R-385-1-1-63, Amphibious Objective Study (AOS) (U) (Classified SECRET).

11. AAS-58 Amphibious Area Study (U) (Classified SECRET) By G-2 FMFLANT & NAIRU-79-1.

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